

# The Radio Sky



Figure 1—A false-color image of the entire radio sky, observed at 408 MHz; this image is available on the World Wide Web.<sup>6</sup> The coordinate system is RA,dec, with RA = 0 h, dec = 0° at the exact center of the picture. The angular resolution of this image is 0.85°. Strong emission from the plane of our galaxy (the Milky Way) is clear; the galactic nucleus, Sagittarius A, is at lower right in this image. Two strong discrete sources, Cassiopeia A and Cygnus A, appear as white dots near the top of the picture, just to the right of center. Note that, although strong emission occurs close to the galactic plane, there is measurable radio emission over the entire sky.

Sky radiation may limit the performance of your station.  
Part 1 of this two-part article explains global measurements  
and how much sky noise to expect at your station.

**F**rom the early 1930s, we have known that broadband radio radiation from the Milky Way may be a limiting factor in the signal-to-noise ratio (S/N) attainable on communications links, both terrestrially and in space. Relatively recent radio-astronomical measurements of the entire sky have characterized this radiation more precisely, and in greater detail than had been available before. Recent data presented here allow you to estimate easily the likely impact on a given communication link. I'll also show the influences of frequency, antenna beamwidths, time of day and season. Although moon-bounce operators, with their sensitive receivers and high-gain antennas, are well aware of the importance of this background radiation, it can also be important for terrestrial communication using today's average receiver sensitivity and even with very small antennas. Simple equipment can map the sky background; in Part 2 we'll compare measurements made with my very simple receiving system to the standard database.

### The Background Radiation

Karl Jansky<sup>1</sup> was the first to discover the extraterrestrial nature of the background sky

noise. In a project funded by Bell Laboratories to investigate the limiting S/N of short-wave transatlantic telephone circuits, Jansky constructed a rotatable Bruce-array beam antenna for 20.5 MHz and showed that background radio noise peaked in the direction of the Milky Way's center. A good description of the discovery is available,<sup>2</sup> and a recent analysis of Jansky's chart recordings shows how well his early results correspond with more recent observations.<sup>3</sup> A brief summary of radio astronomy appears in *QST*'s July 1995 issue.<sup>4</sup>

Since Jansky's 20.5-MHz observations, there have been many surveys of the galactic background radiation, at frequencies from a few megahertz to several gigahertz. Very few of these surveys are complete, in that they may have included observations from either the Northern or the Southern Hemisphere, but not both. Others were created as a composite picture combined from observations at different frequencies and with different telescopes, with assumptions about how the radiation changes with frequency. Some surveys have been confined to the galactic plane. Others have been very sensitive to discrete background sources but ignored the large-scale distribution of emission. Nevertheless, the general features of the radio background and how those features vary with frequency

have become well established.

In 1981, a new and complete survey of the entire radio sky was published.<sup>5</sup> This was the result of some painstaking work carried out over a decade by a group of radio astronomers who used the world's biggest fully steerable radio telescopes—the Jodrell Bank 76-meter antenna in the UK, the Effelsberg 100-meter antenna in Germany, and the Parkes 64-meter antenna in Australia—to make a carefully calibrated survey of sky emission at 408 MHz, covering both Northern and Southern Hemispheres. These observations have become the definitive survey of the extended, broadband radio-sky background emission at this wavelength, a standard database to which other researchers refer. The data are now in the public domain and available to anyone with access to the World Wide Web.<sup>6</sup> As well as being probably the most precise data available, the survey frequency of 408 MHz is especially convenient for radio amateurs; it allows a good estimate of what to expect in the neighboring amateur bands. The radiation detected is very broadband; its intensity decreases with increasing frequency, but the general picture changes remarkably little from a few megahertz up to many gigahertz. Sironi<sup>7</sup> and Webster<sup>8</sup> have made measurements of the background using scaled antennas at a vari-

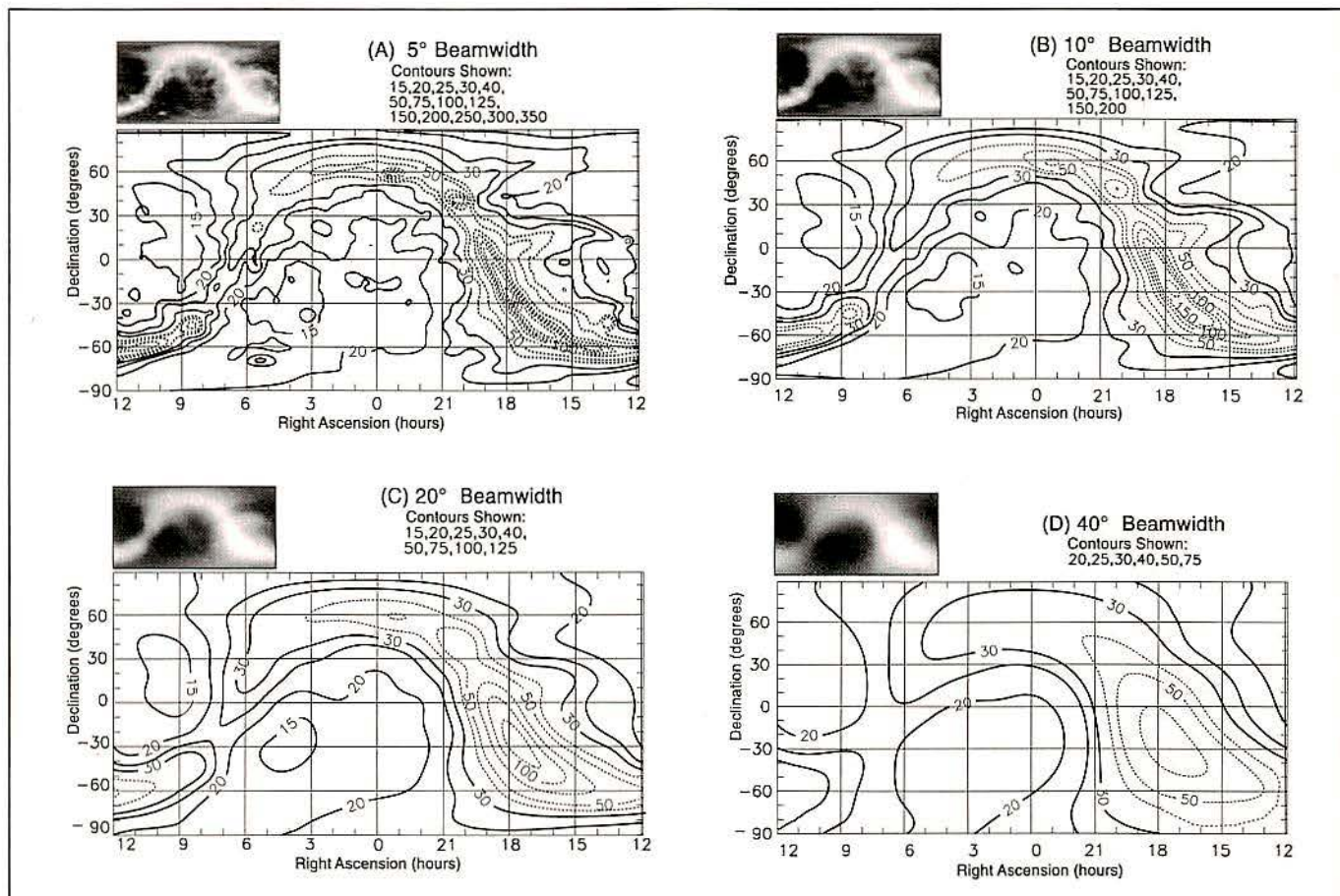


Figure 2—Gray-scale images and contour plots show the expected sky brightness temperature at 432 MHz, for beamwidths from 5 to 40°. Contours of 40 K and greater are drawn as dashed lines. Contours show the level of sky noise collected by an antenna pointing in any specific direction. As with Figure 1, the coordinates are RA, dec (epoch B1950), with RA = 0 h, dec = 0° at the center. Sagittarius A, the galactic nucleus at RA = 17.8 h, dec = -28.9° (epoch J2000), is the strongest source of emission in each plot.

ety of frequencies; they discuss how the emission changes in intensity and distribution, compared with 408 MHz, at frequencies from 17.5 MHz to 1407 MHz. The changes are relatively subtle, however, and it is safe for the average radio amateur to assume the general distribution of emission remains much the same at all these frequencies, and that we can derive the intensity at any chosen frequency from the 408-MHz emission by means of a suitable scaling factor. One important exception is the 21-cm emission from galactic atomic hydrogen close to 1420.4 MHz, which is generally much brighter than the extended broadband emission at that frequency; we consider only the broadband radiation in this article.

I downloaded the lead photo for this article (Figure 1) over the World Wide Web. It shows a false-color image of the entire sky at 408 MHz, as observed with a telescope beamwidth of  $0.85^\circ$ . Over the many years it took to accumulate the data, the observers were careful to avoid contamination of the background emission by solar or planetary emissions. Apart from that, this image shows the whole universe! Most of the emission comes from synchrotron emission, or high-energy electrons spiraling in magnetic fields between the stars in our own galaxy, but these measurements include *all* radio sources in the universe beyond the solar system and visible from the Earth. This image uses the right-ascension, declination (RA,dec) coordinate scheme. RA is a measure of celestial longitude, and dec of latitude. Part 2 of this article and the "Sky Noise" information package from ARRL Headquarters<sup>9</sup> describe conversion between these coordinates and azimuth and elevation at your location. RA is measured in hours. The Local Sidereal Time (LST) at which a source crosses the meridian and reaches its highest point in the sky, corresponds to the RA of that source. The meridian is the line running from north to south, passing directly overhead through the zenith. Note that RA increases from right to left in the image. The dec is simply the angle of the source north of the plane of the Earth's equator. The bright S-curve of emission extending across the picture is the emission from the plane of our Milky Way. The strongest part of the curve, in the lower right, comes from the center of our own galaxy.

Figure 1 demonstrates a very important feature of the background radiation; as well as very small-scale features and discrete radio sources—that is, sources much smaller than the antenna beamwidth—there is emission along, and even well away from, the galactic plane. A relatively large antenna may be required to detect the discrete sources, but the extended emission can fill the beam of even very small antennas. You do not need a big antenna to detect, and be limited by, the radio noise from the Milky Way. The noise picked up from this celestial emission adds directly to your receiver noise.

### Sky Intensities

We usually express the intensity of extended radio emission from the sky in terms

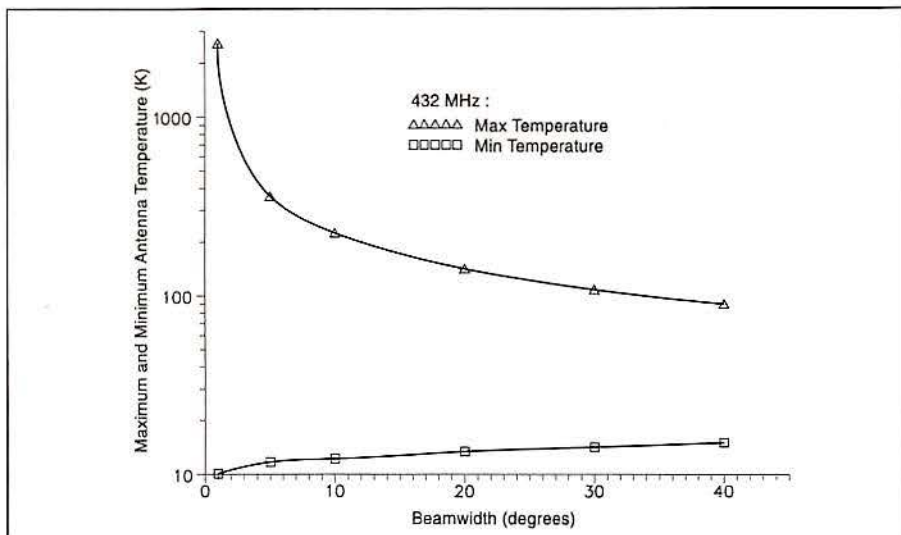


Figure 3—The effect of antenna beamwidth on the expected antenna temperatures, that we might observe at 432 MHz. Note the logarithmic intensity scale. While the minimum sky temperature changes relatively little, from 15 K with a  $40^\circ$  beam down to 10 K with a  $1^\circ$  beam, the peak temperatures vary from ~90 K ( $40^\circ$  beam) up to ~2500 K ( $1^\circ$  beam). For all but the smallest beam size, the galactic nucleus gives the highest antenna temperature. With an angular resolution of  $1^\circ$  or better, the discrete source Cassiopeia A becomes the brightest point in the radio sky at this wavelength.

of a *brightness temperature*. When the radio power received by the antenna is equal to the thermal noise power available from a resistor at temperature  $T$  kelvins, we say the *antenna temperature* is  $T$  kelvins, and—neglecting losses—the observed sky brightness is also  $T$  kelvins. The actual power received,  $P$  (in watts), can be calculated from

$$P = k \times T \times B$$

where

$k$  is Boltzmann's constant:

$$k = 1.38 \times 10^{-23} \text{ joules per kelvin and}$$

$B$  is the bandwidth in hertz.

In practice, the antenna temperature observed from the sky depends not only on the background sky temperature, but also on the antenna beamwidth. The background power collected by the antenna is a weighted average of all emissions within its main lobe and all sidelobes.

As an example, with an antenna pointing at the ground, which we assume to be totally absorbing and at 290 K ( $17^\circ\text{C}$  or  $63^\circ\text{F}$ ), the total power received in a bandwidth of 3 kHz would be:

$$P = k \times T \times B = 1.38 \times 10^{-23} \times 290 \times 3000 = 12 \times 10^{-18} \text{ W (or } -139.2 \text{ dBm)}$$

With today's sensitive receivers, this noise power is likely to be much greater than the internal noise generated by the receiver.

If we point the same antenna exactly at the horizon, then half its beamwidth would see "hot" ground and the other half would see the sky. This would reduce the antenna component of noise power from the ground radiation by one-half.

### The Effect of Antenna Beamwidth

Figure 1 shows some very extended fea-

tures that spread over tens of degrees, as well as several discrete sources that are much smaller than the  $0.85^\circ$  antenna beam. If we point a large-beamwidth antenna toward very extended features, the observed antenna temperature nearly equals the true background sky temperature in that direction, if that sky emission nearly fills the antenna's main beam. If we point the same antenna toward a discrete source, however, the source temperature averaged over the broad antenna beam is substantially reduced—by a factor proportional to the area of the antenna beam compared with the area of the source. This beam-averaging effect makes an important difference in observed antenna temperatures. This has been simulated, using a computer program to smooth the data shown in Figure 1, to show what might be seen with relatively small antennas.

Figure 2 shows how the sky background appears to antennas with beamwidths of 5, 10, 20 and  $40^\circ$ , representative of what might be seen by amateur antenna systems operating at wavelengths from a few centimeters to a few meters. We can use the contours of Figure 2 fairly precisely to estimate the antenna temperature at 432 MHz in any chosen direction. The gray-scale images give an overall impression of how the emission varies over the sky. Each image depicts the entire sky—in an RA,dec coordinate system—as in Figure 1. Even the  $40^\circ$  beamwidth clearly shows the emission from the Milky Way. The strongest emission peaks in the direction of Sagittarius A, toward the center of our galaxy; this is at 17.8 hours RA and  $-28.9^\circ$  dec.

With a  $10^\circ$  or smaller beam, you can see some of the stronger discrete sources, such as Cygnus A at RA 20.0 h, dec  $40.7^\circ$ , and Cassiopeia A at 23.4 h,  $58.8^\circ$  (J2000).<sup>10</sup> With a

0.85° beam (Figure 1), the peak antenna temperature in the direction of Cassiopeia A, corrected to 432 MHz, is 3900 K. Averaged over a 10° beamwidth (Figure 2B) the brightness in that direction is reduced to 80 K, but some 50 K of that comes from the extended galactic plane, rather than Cassiopeia A itself. The true angular size of this source is about 0.1°, much less than even the 0.85° beam of Figure 1. Averaging over a 10° beamwidth, instead of the 0.85° beamwidth, dilutes the intense emission from this small radio source by a factor of ~140.<sup>11</sup> The very extended emission from the galactic plane, on the other hand, can fill much of a 10° beamwidth. So, the beam-averaging effect on the general galactic background, although still present, is much less pronounced. Figure 3 shows the maximum and minimum antenna temperatures that we would observe from the sky at 432 MHz with beamwidths from 1 to 40°.

Note that if you want to receive radio signals from a satellite that happens to be in the direction of a radio-bright part of the sky, a larger antenna may not help. For example, at 432 MHz, a 16-foot dish would have a beamwidth of about 10°. From Figure 2B, the antenna temperature measured with this antenna in the direction of the galactic center would be ~220 K. An antenna with a 40° beamwidth—eg, a small Yagi or a four-foot dish—would only give an antenna temperature in this direction (from Figure 2D) of ~90 K. With a sensitive preamp and even with this 40° beam, the sky noise should exceed receiver noise in the direction of the galactic center. The antenna noise has decreased by 4 dB with the smaller antenna. Now an antenna with a 10° beam should have 12.0 dB more gain than a 40° antenna. Neglecting the contribution from receiver and other sources of noise, however, the improvement in S/N with the larger antenna would only be about 8 dB (12 - 4). Allowing for receiver noise, the additional degradation will not be quite so dramatic in practice, but it will probably still be significant. EME operators are fortunate; the Moon never passes in front of the galactic center. It can come within 10°, however, so considerations like these are not entirely academic.

Although you may not always obtain quite the S/N improvement that you had expected in some directions with a larger antenna, this is more than offset by those times you gain more than you expected. From Figure 2, an antenna with a 10° beamwidth pointed at the wing of the galactic center (about 20° from the galactic plane), will receive about 30 K of antenna noise. A 40° beamwidth will collect about 50 K—~2.4 dB more. Again ignoring receiver noise, the 16-foot dish will potentially improve S/N in this direction by about 14.4 dB (12.0 + 2.4), rather than just the 12.0 dB expected from antenna gain alone. In this example, the high background noise in the direction of the galactic plane has entered into the 40° beam and its sidelobes, to make the S/N somewhat worse than expected. In practice, the precise degradation depends on the details of the sidelobes

of the two antennas being compared, and on the exact importance of the receiver and other noise sources.

The situation is a little complicated. When estimating achievable S/N on a weak-signal satellite link or for EME operation, consider the detailed structure of the background radiation, and its relation to antenna beamwidth and sidelobes. Figure 3 shows the sky background at 432 MHz with beamwidths from 5 to 40° (roughly, effective antenna diameters from ~14 to ~1.7 wavelengths). Part 2 of this article describes how sky background noise varies with time of day and frequency.

#### Notes

<sup>1</sup>Karl G. Jansky, "Directional Studies of Atmospherics at High Frequencies," *Proceedings of the Institute of Radio Engineers*, Vol 20, 1932, pp 1920-1932.

<sup>2</sup>Woodruff T. Sullivan III, "Karl Jansky and the Discovery of Extraterrestrial Radio Waves," *The Early Years of Radio Astronomy* (Cambridge University Press), 1984, p 3.

<sup>3</sup>Woodruff T. Sullivan III, "A New Look at Karl Jansky's Original Data," *Sky and Telescope*, no. 56, 1978, pp 101-105.

<sup>4</sup>Robert Welsh, N3RW, "Radio Astronomy and the Radio Amateur" *QST*, Jul 1995, pp 46-48.

<sup>5</sup>C. G. T. Haslam, U. Klein, C. J. Salter, H. Stoffel, W. E. Wilson, M. N. Cleary, D. J. Cooke and P. Thomasson, "A 408 MHz All-sky Continuum Survey," *Astronomy and Astrophysics*, Vol 100, 1981, p 209.

<sup>6</sup>World Wide Web site: <http://skview.gsfc.nasa.gov/cgi-bin/skvbasic>. You can download the astronomical data as a GIF file, or as a FITS-format data set. Many different astronomical databases are available from this site.

<sup>7</sup>G. Sironi, "The Spectrum of the Galactic Nonthermal Background Radiation—I," *Monthly Notices of the Royal Astronomical Society*, Vol 166, 1974, p 345.

<sup>8</sup>A. S. Webster, "The Spectrum of the Galactic Nonthermal Background Radiation—II," *Monthly Notices of the Royal Astronomical Society*, Vol 166, 1974, p 355.

<sup>9</sup>Contact the Technical Secretary at ARRL Headquarters (by any means described on page 10 of this issue) and request the June 1996 QST Sky Noise template. ARRL members send \$2 (nonmembers, \$4) for shipping and handling.

<sup>10</sup>Parenthetical references such as B1950 and J2000 define the astronomical epoch of the associated coordinates. The epochs are needed for precise telescope positioning, but are insignificant for Amateur Radio work.

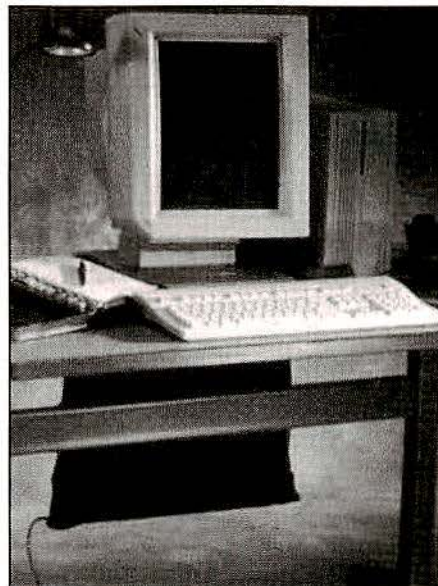
<sup>11</sup>Scientists use the symbol "—" as shorthand for "on the order of."

*Darrel Emerson was first licensed in 1964 as G3SYS, and still holds that call sign. He holds a BA in natural science from the University of Oxford, and a PhD in radio astronomy from the University of Cambridge, England. After spending several years working in Germany and France, he moved to Arizona in 1986, becoming AA7FV. He now works for the National Radio Astronomy Observatory in Tucson, Arizona, working primarily with the 12 Meter Telescope at Kitt Peak. Most of Darrel's Amateur Radio activity involves listening for very weak signals of all kinds; CW is his preferred operating mode. Darrel lives at 3555 E Thimble Peak Pl, Tucson, AZ 85718. You can reach him by e-mail at [aa7fv@amsat.org](mailto:aa7fv@amsat.org) or on CompuServe as member number 74010,2230. **QST***

## New Products

### CABLE KEEPER ELIMINATES COMPUTER AND HAM SHACK WIRING MESS

◊ Here's a solution to the messy tangle of wires and cables that pile up behind and beneath the typical personal computer desk or ham shack table. Cable Keeper from Watson Furniture Systems keeps cables and wires out of sight, improving safety and decor, and making cleaning a lot easier. The unit is a framed black bag, 18 1/2 x 13 inches, that hangs beneath the desk and conceals cables from computers and ham gear. Cable Keeper has a portfolio-style spring-loaded metal closure mechanism along the top. Openings along its sides let you easily route cables into and out of the bag, which hold that portion of the wire or cable that normally sags behind your work station or ham shack desk or onto the floor and can be unsightly. Two hooks to hang the bag and even a nail to set pilot holes for the hooks are thoughtfully included. The design recently won a Consumer Products Award of Merit from the Industrial Designers Society of America, Northwest Chapter. A patent is pending.



Cable Keeper is \$34.95 from Watson Furniture Systems, 12715 Miller Rd NE, Bainbridge Island WA 98110; tel 800-426-1202 or <http://www.cablekeeper.com> on the World Wide Web.

### RAC 'N ROLLUP BY N2CKH

Here's a Windows front-end program for the 1996 *Radio Amateur Callbook* CD-ROM that lets you look up US or foreign stations by call sign without having to switch between databases. The utility displays country, continent and CQ Zone, and has a grid-square locator for US stations. In addition, RAC 'n Rollup provides mailing label printing and clipboard copying for QSLs.

It's \$9.95 plus \$1.50 for shipping within the US, \$5 for overseas orders, from Stephen B. Hajducek, N2CKH, PO Box 8, Morganville, NJ 07751-0016; ByteWise BBS, 908-363-2760; e-mail [info@bytewise.org](mailto:info@bytewise.org). **QST**

# The Radio Sky

This article concludes Darrel Emerson's discussion of background noise that began last month in *QST*. As he continues, Darrel refers to Figures 1 through 3. Those figures and Notes 1 through 11 appear in that article.—Ed.

## Converting Between Sky-Coordinate Systems

Figures 1 and 2 show the distribution of sky background radiation on the RA, dec coordinate system.<sup>12</sup> To estimate the effect on a given communication link, it is usually more convenient to use an azimuth-elevation (az-el) coordinate system at the station. Figure 4 shows the 20° beamwidth data from Figure 2C, plotted at two-hour intervals throughout the day for a station at 40° N latitude. (For beamwidths likely with most amateur antennas, the plots are accurate enough for any latitude within the continental US.) It's easy to compare features on Figures 2C and 4 because the two maps use the same contour levels.

Figure 4 shows plots for one day of *local sidereal time* (LST) at two-hour intervals. Figure 5 shows the mean sidereal time at the Greenwich meridian (GMST) at 0000 hours UTC for each day of the year. (This chart is accurate to within a few minutes for any year.) To find your current approximate LST, use  $LST \approx GMST (0000h) + UTC + (\text{longitude}/15)$ , where west longitudes are negative. For example, let's calculate the LST for 1500h EDT on June 1 at Newington (72° 45' W). The GMST at 0000h UTC from Figure 5 for June 1 is 1640h. Then add the current UTC ( $1500 + 0400 = 1900$  UTC) in hours to this GMST, and further add  $(\text{longitude}/15 = -72.75/15 = -4.85)$  hours, where the longitude is that for your location, measured in degrees, with west longitude having negative values. This gives  $16.7 + 19.0 + (-4.85) = 30.85$  or 3051h. Since this is greater than 2400h, we must subtract 24 hours, to get 0651h LST. Once you have calculated *your* LST, the plot from Figure 4 that is closest to your LST approximates the radio sky above your head. If you want to convert RA, dec coordinates more precisely, get the "Sky Noise" information package from ARRL Headquarters.<sup>13</sup> Two simple BASIC programs are available as well. One program converts between RA, dec and az-el coordinates; the other collects sky-map data from an ICOM R-7100 interfaced to a PC. (See Note 13.)

<sup>12</sup>Notes appear on page 31.

Part 2 concludes this series by discussing antenna headings for celestial noise sources; sky-noise variation with frequency; solar and terrestrial noise. Combine these topics to map sky noise at *your* location and apply the results.

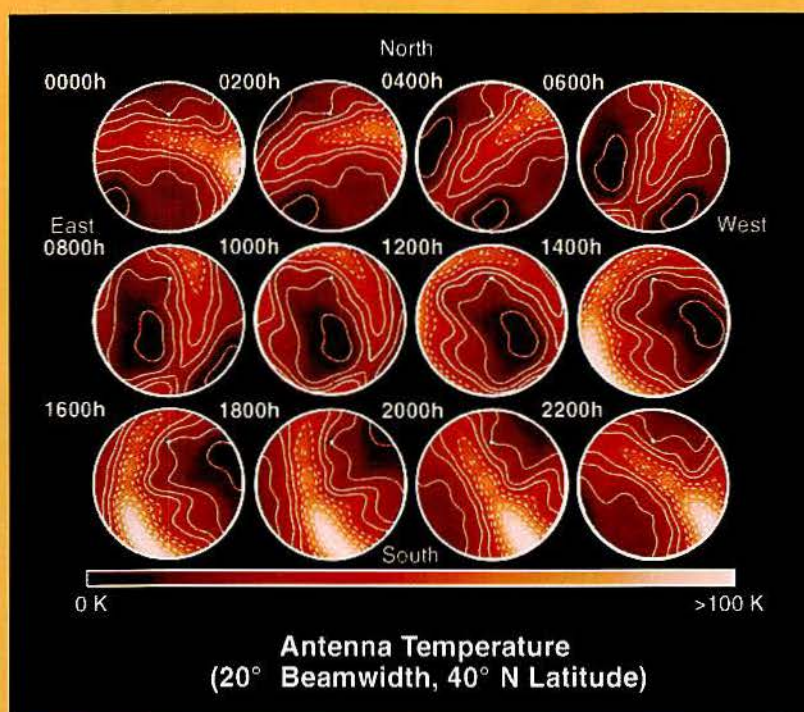


Figure 4—Contours overlaid on false-color plots of the radio sky at 432 MHz for two-hour intervals throughout the local sidereal day. The data from Figure 2C (contours for 15, 20, 25, 30, 40, 50, 75, 100, 125K) have been translated into az-el coordinates, and plotted with the zenith in the center and the horizon around the perimeter of each plot. This gives a fisheye view of the radio sky, as would be seen with radio eyes, lying on your back, with your feet to the south. As in Figure 2, contours for 40 K and greater are dashed. Times are in LST. It's easy to see the galactic plane rotating. At 1400h LST, the galactic plane lies all along the eastern horizon. Reception of terrestrial signals from these directions will be very noisy around 1400h LST. Just before 1800h LST, the bright galactic nucleus reaches its highest elevation, in the south.

## Variation with Frequency

The radiation shown in Figures 1 and 2 is very broadband, but its absolute intensity changes gradually with frequency. Every time the frequency is doubled, the sky temperature of the galactic background decreases by a factor ~5 to 7; this factor changes slightly with frequency, too.<sup>14</sup> Figure 6 shows the maximum and minimum antenna temperatures expected with antenna beamwidths of 1°, 5°, 20° and 40°, from 28

MHz up to 2.4 GHz. I derived these temperatures from the smoothed intensities of Figure 2 and then scaled them according to frequency, using factors from the astronomical literature. (See notes 7 and 8 in Part 1.)

Emissions from the Milky Way dominate the radio sky up to UHF, but the 2.7 K cosmic background radiation becomes important above ~600 MHz. Penzias and Wilson received a Nobel prize for discovering this noise in 1965, at 4 GHz. Astrono-

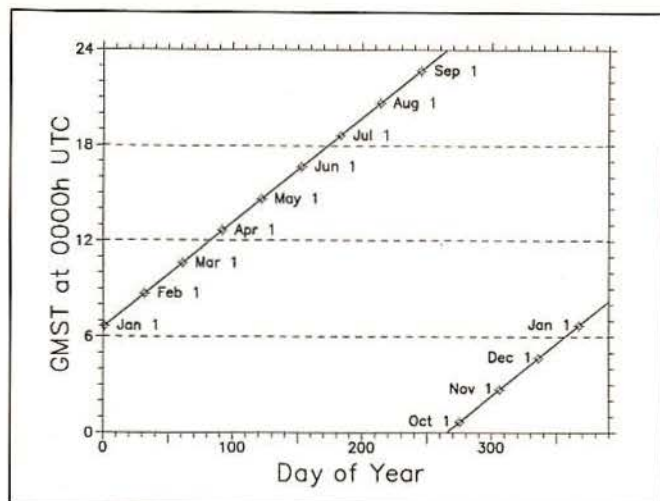


Figure 5—LST: the graph shows GMST, the sidereal time at Greenwich (longitude 0°) at 0000h UTC for every day of the year. Although calculated for 1996, the plot is correct to within a few minutes for any year. The text tells how to find your approximate LST.

mers consider it to be the cooling relict of the Big Bang. At the 13-cm amateur band and at shorter wavelengths, this cosmic background radiation swamps emission from the Milky Way—at least with common amateur antenna beamwidths. The Sky Noise package (see Note 13) tells how radio-sky intensities were scaled to different frequencies, both to derive expected intensities at 432 MHz (Figures 2 to 4) from the measurements of 408 MHz, and to produce the data plotted in Figure 6. Note that above about 1 GHz, noise from the atmosphere can also begin to become important. It can give a few kelvins of additional noise beyond that plotted in Figure 6.

## Solar Radiation

The distribution of emission discussed so far has not included our Sun, often the brightest object in the radio sky. The Sun moves about a degree per day with respect to the sky background, and the strength of solar radiation varies greatly at radio wavelengths.

Figure 7 shows the antenna temperature expected from the Sun (see Note 15) over a wide range of frequencies, for an antenna gain of 10 dBi, such as a typical five-element Yagi. The antenna temperatures are proportional to antenna gain. For an antenna gain of 16 dBi (an increase of 6 dB), the solar signal would be four times greater than that shown in Figure 7.

The two lower solid lines show the range of signal expected from the quiet Sun at different phases of the sunspot cycle, including a component for the slowly varying emission. The upper dashed line shows the amplitude of a typical outburst; at 50 MHz this can be more than 1000 times more intense than the normal solar radiation. A five-element Yagi—or even a single dipole—would easily detect it. A comparison of the solid lines in Figure 7 with

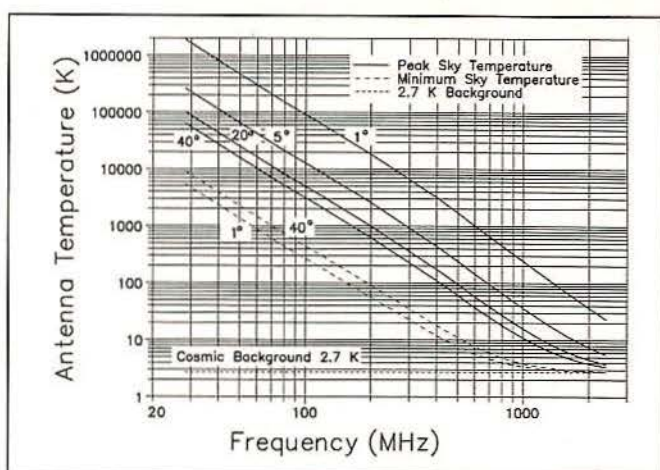


Figure 6—The maximum and minimum sky temperatures for antenna beamwidths of 1°, 5°, 20° and 40°, at frequencies from 28 MHz to 2.4 GHz. Note the logarithmic axes; the peak temperature ranges from about 1,000,000 K at ~30 MHz to only a few kelvins at 2 GHz. Except for the 1° beamwidth, the brightest emission is always the galactic center. Even with the relatively broad 40° beamwidth, there is still a ratio of 6:1 or 7:1 between the maximum and minimum antenna temperatures over most of this frequency range. At about 1 GHz and above, the 2.7 K cosmic background radiation dominates the lowest sky temperature. This plot does not include additional noise from terrestrial sources: atmosphere, ionosphere or ground.

Figure 6, however, shows that—with the modest 10 dBi of antenna gain—the radiation from the quiet Sun at 50 MHz could be difficult to distinguish from the general galactic radiation.

The radio emission from the Sun can be useful for a rough check that a receiving system is operating correctly.<sup>16,17</sup> The emission can be so variable, however (on time scales ranging from seconds to years), that it is of limited use for absolute calibration of antennas or receivers.

## Noise from the Atmosphere

Even at frequencies below 1 GHz, the Earth's atmosphere gives slight attenuation to radio waves. The loss of signal is usually insignificant at these frequencies, but the extra noise radiated from the atmosphere as a result of the attenuation can be very significant.

The source in Note 18 gives the extra antenna temperature expected from oxygen and water vapor in the atmosphere. At the zenith (minimum path length through the atmosphere) the extra noise is ~1.2 K at 500 MHz and ~2.4 K at 2.4 GHz. This noise comes almost entirely from oxygen rather than water vapor, so it is fairly independent of local weather conditions. Extra noise and attenuation from atmospheric water vapor becomes important at even higher frequencies.

The extra noise is approximately proportional to the path length through the atmosphere, and above a few degrees of elevation, the path length is proportional to  $1/\sin(\text{elevation})$ . Operators must consider the curvature of the Earth at very low elevation angles (see Note 18), but that is be-

yond the scope of this article. At 30° elevation the atmospheric noise is twice that at the zenith, becoming ~2.4 K and ~4.8 K at 500 MHz and 2.4 GHz, respectively. At 5° elevation the contributions become ~13.5 K and ~25 K.

Atmospheric noise increases quite sharply at even lower elevations, simply because of the extra path length through the atmosphere. The extra noise experienced in practice will be an average of the noise from the range of elevation angles accepted by the antenna. Narrow beams pointing at the horizon see only very long paths through the atmosphere and so collect more atmospheric noise than wider beams. Hence, the S/N improvement for larger antennas (narrower beamwidths) pointing at the horizon can be somewhat less than expected.

## Ground Radiation

The Earth's surface effectively glows at radio wavelengths, giving off "black body" radiation corresponding, for 100% absorbing ground, to the local ground temperature in kelvins (~290 K, about 17°C or 63°F). For an antenna pointed at the horizon, half of the main and side lobes will pick up ground radiation, adding ~145 K to the system noise. Thus, the noise temperature for a station might be 35 K (0.5-dB noise figure), yet it would become at least 180 K (145 K + 35 K) for terrestrial communications. Any radiation from the Milky Way, the Sun or the Earth's atmosphere will further increase the noise temperature. The system noise decreases when you point the antenna upward, toward your favorite satellite, but many of the side lobes may include ground. Remember, it's not just the

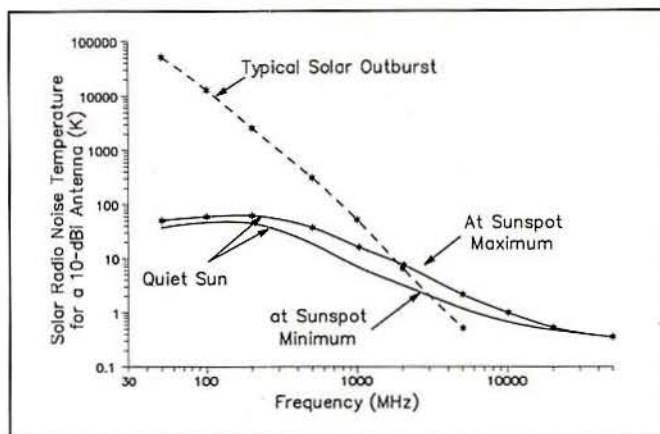


Figure 7—The range of antenna temperatures expected from the Sun, as a function of frequency, using a 10-dBi-gain antenna (derived from the source in Note 15). The lower solid line shows the emission of the quiet Sun at sunspot minimum. The upper solid line shows the quiet Sun near sunspot maximum, including the slowly varying emission and assuming a sunspot number,  $R$ , of  $\sim 100$ . The upper, dashed line shows the strength of a typical outburst.

peak side lobe that counts, but the total energy received in *all* sidelobes. The brightness levels plotted in Figure 2 show that ground radiation is likely to be much more serious than the celestial background emission at 430 MHz and higher frequencies, except when the antenna is pointing toward the Sun or at our galactic nucleus, Sagittarius A.

Figure 6 shows that at wavelengths of 2 meters and greater most of the background sky has a radio temperature much higher than that of the ground. At these lower frequencies, the ground looks cold in comparison to the sky; the Earth shields the antenna from some of the noisy sky radiation.

The ground radiation in Figure 8 very clearly dominates the 434-MHz measurements of the sky made at AA7FV. We'll discuss this more later.

### How Relevant is All This to the Average Radio Amateur?

Lest it be thought that all this is only important to the EME operators with huge antennas and the very ultimate in receiving equipment, Figures 8 and 9 show results obtained at AA7FV with what would be considered a rather poor amateur 70-cm receiving setup.

The antenna is an eight-element Yagi for 70 cm, barely five feet long. Its specified gain is 14.6 dBi, and 30 feet of coax connect it to a preamp in the shack. The digitized AGC voltage of the receiver, an ICOM R-7100, is available at its standard CI-V interface. A PC recorded the receiver AGC level continuously ( $\sim 27$  samples per second), while the antenna was slewed across the sky. It takes about one minute to slew my antenna through  $360^\circ$  in azimuth; I collected data at  $10^\circ$  elevation intervals from  $0$  to  $90^\circ$ . It took 10 minutes to make a complete map of the visible sky. The receiver bandwidth was about 200 kHz.

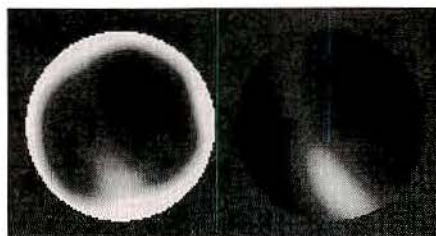


Figure 8—The left image is a gray-scale display of total system noise for the entire visible sky at about 1800h LST from AA7FV (latitude  $32.33^\circ$  N), observed with an eight-element Yagi antenna at 434 MHz. The image orientation is like that of Figure 4. The right image is a simulation based on the 408-MHz data from Figure 1. (See text.)

I carefully calibrated the digitized AGC level from the R-7100, so that the PC logging program could convert the AGC values into receive-system noise level in kelvins. The total receiver noise includes preamp noise, cable and other losses, added to all the ground, atmospheric and celestial radiation entering the antenna beam and its sidelobes. The PC later interpolates the recorded data to a regular az-el grid.

The AGC values are rather coarsely digitized, with about 21 units for a 10-dB change in receiver noise. Fortunately, receiver noise contributes a certain amount of "dithering," to produce a much finer resolution of very small changes in the total receiver noise level.

The most difficult problem was overcoming man-made noise. At 70 cm, the worst interference encountered was from my own data-logging PC. It was helpful to use the slowest PC available (a 12-MHz 286 laptop) with all computer cables filtered, and with the PC inside a screened enclosure. Even with these precautions, some radiation from the PC and other ter-

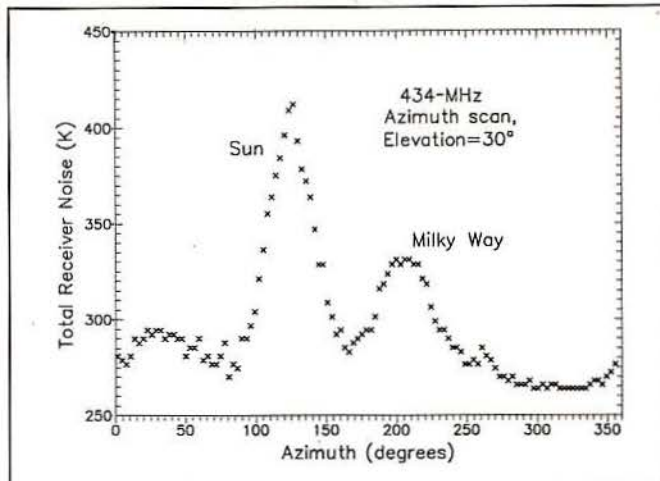


Figure 9—A one-minute record of the receiver AGC response, at 434 MHz, as the antenna rotates  $360^\circ$  in azimuth at  $30^\circ$  elevation. Note the increases in noise temperature as the antenna crosses the Sun at azimuth  $\sim 126^\circ$ , then the galactic plane at azimuth  $\sim 205^\circ$ .

restrial interference was detectable in the strongest sidelobes of the antenna, but at a level several decibels below the average sky background noise. The observation centers on 434 MHz, which had, on average, the lowest level of terrestrial interference at AA7FV.

Figure 8 (left) shows the radiation from the entire visible sky mapped by my antenna at 434 MHz in July 1995. Its presentation is similar to that of Figure 4. The ground radiation is very obvious as the bright rim around the perimeter of the radio photo. Towards the south, however, you can see clearly the radiation from the Milky Way peaking toward the center of our galaxy, a few degrees above my horizon. I made this map at about 18 hours LST, which occurred then just before local midnight; obviously the Sun is not visible in the data.

Figure 8 (right) shows a simulation of what the sky should look like at 434 MHz from Tucson then, but it does not include ground radiation. I smoothed the data from Figure 1 to a  $30^\circ$  beamwidth, matching my own antenna. I plotted the data as for the left image, adjusted for the same time of day and year. Apart from the very strong ground radiation at low elevations in my measurements, the two pictures agree surprisingly well.

Figure 9 shows the variation in noise power from the receiver recorded on February 26, 1995, at about 9:40 MST, when the local Sun elevation was about  $31.2^\circ$ . The antenna was scanned in azimuth, at a fixed  $30^\circ$  elevation. Even with this poor receiving station, the increase in noise temperature from both the Sun and the galaxy is very obvious. The direction of the noise peaks changed with time, at the expected rate of  $15^\circ$  per hour, corresponding to the rotation of the Earth. (Terrestrial interference would have remained fixed in direction.) The antenna beamwidth, measured

from the width of the peak in Figure 9 as the beam passes over the Sun, is about 30°.

The ground radiation has different intensities in different horizontal directions. The direction of the strongest ground noise corresponds exactly with the highest mountain peak visible from my location: to the northeast, up to about 15° elevation. Closer local obstacles, such as a neighbor's tree, appear as thermal noise at 434 MHz. For terrestrial VHF and UHF communications, I have an exceptionally poor location.

## Conclusions

We can quite easily detect the complex radio sky background—even with very simple communications equipment. Although only relatively large antennas can detect discrete celestial sources, the extended radio emission from our own galaxy can be measured even with a tiny antenna. At least up to ~430 MHz, the sky background noise may set the limiting sensitivity of either terrestrial or space communications links, with large or small antennas and even with relatively poor receivers. For the best sensitivity in receiving space communications at 430 MHz and above, the average side lobe level of an antenna may be a much more important parameter than

its forward gain.

Even relatively primitive equipment can map the sky background. I made Figure 8 by scanning the sky at 434 MHz with a single eight-element Yagi, only five feet long. The figure clearly shows the relatively bright galactic nucleus in the south, with the Milky Way extending across the sky to the northeast. A larger antenna would show more detail and be less susceptible to ground radiation at low elevation angles, but it would be—on average—just as susceptible to S/N degradation from the noise of the sky background.

## Acknowledgments

I want to thank Dr. Chris Salter from the Arecibo Observatory for many enlightening discussions, and for help in defining the spectral index of the galactic background radiation.

## Notes

<sup>12</sup>Darrel Emerson, AA7FV, "The Radio Sky," *QST*, June 1996, pp 32-35.

<sup>13</sup>Contact the Technical Department Secretary at ARRL Headquarters (by any means described on page 10 of this issue) and ask for the Sky Noise package from June 1996 *QST*. The package contains coordinate-conversion equations, additional information that relates sky noise temperature to fre-

quency, coordinate-conversion and ICOM R-7100 interface program listings and a diagram of the author's home sky mapping station. ARRL members send \$2 (nonmembers, \$4) for shipping and handling. Coordinate-conversion and R-7100-control programs are available electronically from the ARRL "Hiram" BBS (tel 860-594-0306), or the ARRL Internet ftp site: [oak.oakland.edu](http://oak.oakland.edu/pub/hamradio/arrl/qst-binaries) (in the [pub/hamradio/arrl/qst-binaries](http://pub/hamradio/arrl/qst-binaries) directory). In either case, look for RADIO SKY.ZIP.

<sup>14</sup>Scientists use the symbol "—" as shorthand for "on the order of."

<sup>15</sup>C. W. Allen, *Astrophysical Quantities* (New York: Oxford University Press, Inc), Third Edition, 1976 (reprinted 1991), pp 192-193.

<sup>16</sup>Bob Atkins, KA1GT, "Noise Temperature, Antenna Temperature and Sun Noise," *The ARRL UHF/Microwave Experimenter's Manual* (Newington: ARRL, 1990; Order no. 3126) pp 7-58 and 7-59; see the *ARRL Publications Catalog* elsewhere in this issue.

<sup>17</sup>David B. Shaffer, W8MIF, "Microwave System Calibration using the Sun and Moon," *The ARRL UHF/Microwave Experimenter's Manual* (Newington: ARRL, 1990; Order no. 3126) pp 7-60 and 7-61; see the *ARRL Publications Catalog* elsewhere in this issue.

<sup>18</sup>D. C. Hogg, "Effective Antenna Temperatures Due to Oxygen and Water Vapor in the Atmosphere," *Journal of Applied Physics*, Vol 30, November 1959, p 1417.

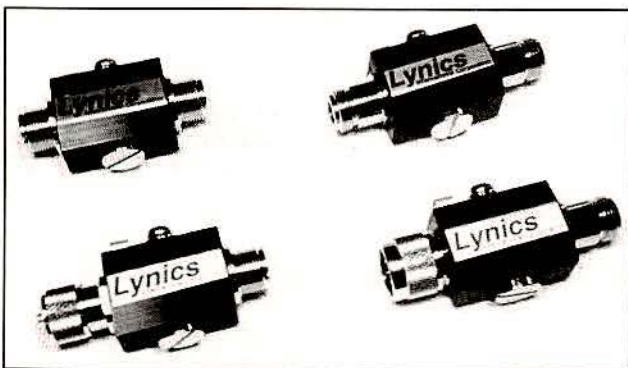
Darrel Emerson, AA7FV, 3555 E Thimble Peak Pl, Tucson, AZ 85718. You can reach him by e-mail at [aa7fv@amsat.org](mailto:aa7fv@amsat.org) or on CompuServe as member number 74010,2230. **QST**

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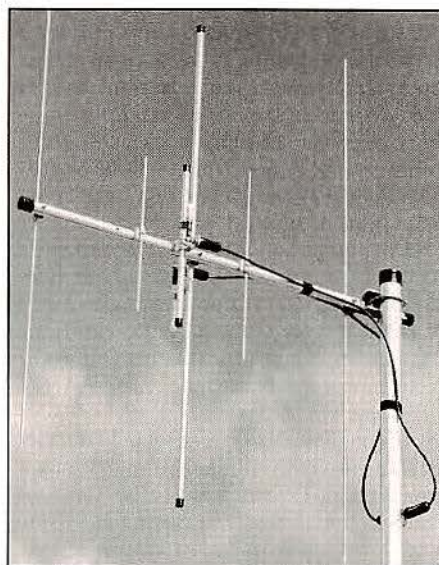
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